WAESD-TR-83-1005
DOE/JPL 955909-83/10
Distribution Category UC-63

LOW COST SOLAR ARRAY PROJECT

CELL AND MODULE FORMATION RESEARCH AREA

PROCESS RESEARCH OF NON-CZ SILICON MATERIAL

QUARTERLY REPORT NO. 5

March 1, 1983 to May 31, 1983

CONTRACT NO. 955909

The JPL Low-Cost Silicon Array Project is sponsored by the U. S. Department of Energy and forms part of the Solar Photovoltaic Conversion Program to initiate a major effort toward the development of low-cost solar arrays. This work was performed for the Jet Propulsion Laboratory, California Institute of Technology, by agreement between NASA and DOE.

Advanced Energy Systems Division
WESTINGHOUSE ELECTRIC CORPORATION
P. O. Box 10864
Pittsburgh, Pennsylvania 15236

LOW COST SOLAR ARRAY PROJECT
Cell and Module Formation Research Area

PROCESS RESEARCH OF NON-CZ SILICON MATERIAL

QUARTERLY REPORT NO. 5
March 1, 1983 to May 31, 1983

Contract No. 955909

The JPL Low-Cost Silicon Array Project is sponsored by the U. S. Department of Energy and forms part of the Solar Photovoltaic Conversion Program to initiate a major effort toward the development of low-cost solar arrays. This work was performed for the Jet Propulsion Laboratory, California Institute of Technology, by agreement between NASA and DOE.

Approved:

C. M. Rose, Manager
Photovoltaic Pilot Operations

Advanced Energy Systems Division
WESTINGHOUSE ELECTRIC CORPORATION
P. O. Box 10864
Pittsburgh, Pennsylvania 15236

TECHNICAL CONTENT STATEMENT

"This report was prepared as an account of work sponsored by the United States Government. Neither the United States nor the United States Department of Energy, nor any of their employees, nor any of their contractors, subcontractors, or their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness or usefulness of any information, apparatus, product or process disclosed, or represents that its use would not infringe privately owned rights."

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

I. CONTRACT GOALS AND OBJECTIVES

The primary objective of this contract is to investigate high-risk, high-payoff research areas associated with the Westinghouse process for producing photovoltaic modules using non-CZ sheet material. All investigations are being performed using dendritic web silicon, but all processes under study are directly applicable to other ribbon forms of sheet material. The contract is separated into the following tasks.

A. Liquid Junction Technical Feasibility Study

The objective of this task is to determine the technical feasibility of forming front and back junctions in non-CZ silicon using liquid dopant techniques. Numerous commercially available liquid phosphorus and boron dopant solutions are under investigation.

Diffusion furnace time-temperature profiles required to achieve a P^+ back surface sheet resistivity of 40 ±10 ohms per square using a boron containing liquid have been determined and verification runs completed. This process is now part of the Westinghouse baseline sequence. Similar studies are underway to achieve the required front surface sheet resistivity.

B. Liquid Diffusion Mask Feasibility Study

The objective of this task was to determine the technical feasibility of forming a liquid applied diffusion mask to replace the more costly chemical vapor deposited SiO_2 diffusion mask. Parameters investigated included SiO_2 containing liquids procured from various vendors, temperature-time profiles for baking liquid masks, film thickness relationship with masking capabilities, identification of etching solutions, process parameters for post-diffusion removal of masks, and methods of liquid mask application. This task is completed and a report issued (Milestone 3).

The liquid SiO_2 diffusion mask is now part of the baseline process sequence.

C. Application Studies of Antireflective (AR) Material Using a Meniscus Coater

The objective of this task, which has also been completed, was to determine the technical feasibility of applying liquid antireflective solutions using meniscus coating equipment. Film thickness relationships with antireflective capabilities have been investigated. The AR films formed have been shown to have uniform thickness along the web and possess the required antireflective properties.

D. Ion Implantation Compatibility/Feasibility Study

In this task, the feasibility of producing uniform high efficiency solar cells from non-CZ silicon using ion implantation junction formation techniques will be established. This task includes an investigation of process variations between processing ion implanted cells and processing gaseous diffused cells using a standard gaseous diffusion process as a baseline and a comparison of cell efficiencies of ion implanted cells with gaseous diffused cells using a standard gaseous diffusion process as a baseline.

The first quarterly report on this task has been issued by Spire Corporation, and additional dendritic web silicon pieces have been supplied to Spire by Westinghouse.

E. Cost Analyses

In this task, SAMICS methodology will be used to quantify production cost improvements associated with process improvements under investigation.

II. SUMMARY

This report describes work performed on JPL Contract No. 955909, Process Research of Non-CZ Silicon Material," during the quarterly period from March 1, 1983 to May 31, 1983.

Technical work this period emphasized preparing the front surface N^+P junction using a phosphorus containing liquid as a diffusant source. These tests have been carried out on hand coated samples using a sponge-squeegee as well as on samples coated using the meniscus coater. Other studies were carried out on a series of liquid boron diffusant sources and liquid mask solutions. A report, "Liquid Diffusion Mask - Technical Feasibility and Test Matrix," was submitted as Milestone 3 as required by the contract.

In addition to the liquid dopant studies, an evaluation was carried out on a vendor supplied pelletized silicon material. This material was evaluated to determine if it could replace the polycrystalline silicon pellets prepared in the shot tower (developed by Kayex Corporation for JPL).

In the work described above, JPL funds are used to define experiments, evaluate data, and report results. All technical and material costs are borne by Westinghouse.

Additional dendritic web was supplied to Spire Corporation for ion implantation studies under JPL Contract 956381.

III. TECHNICAL PROGRESS

1. Meniscus Coater Tests

A meniscus coater was installed during this reporting period and is currently being used for applying liquid dopant solutions to dendritic web material.

In the meniscus coater, the liquid is pumped through a porous stainless steel cylinder, forming a meniscus over the surface. This cylinder then moves under the web surface with only the meniscus touching the web. The web is held in the fixture shown in Figure 1. As many as 10 strips of dendritic web material with lengths up to 16.5 inches can be coated simultaneously in this apparatus. The thickness of the coating can be controlled by the speed of the cylinder and the solution viscosity.

Two 24 strip batches of dendritic web were chosen for the first on site test using the meniscus coater to apply liquid phosphorus. Twenty-four strips were coated with Diffsuion Technology P8 liquid phosphorus solution using the meniscus coater, and 24 strips were given the baseline $POCl_3$ gaseous diffusion. Where possible, matched web crystal pairs were liquid coated and $POCl_3$ diffused. All cells had a liquid boron diffused P^+P junction, and a liquid SiO_2 mask was used. Runs used were designated 0203-1W and 0203-25W. All cells processed in the baseline sequence had sheet resistivities within specification, and no abnormalities were noted.

The results from the coating and diffusion portion of the test were:

a. Problems were encountered with coating the strips with the P8. The strips did not coat uniformly across the holding fixture, and it was necessary to raise the porous stainless steel cylinder. (This in spite of the fact the unit was originally aligned using an antireflective solution.) Because of this, several strips (or portions thereof) were coated more than once. The cause of this problem was the high viscosity of the P8 solution which caused a low and irregular meniscus across the porous cylinder.

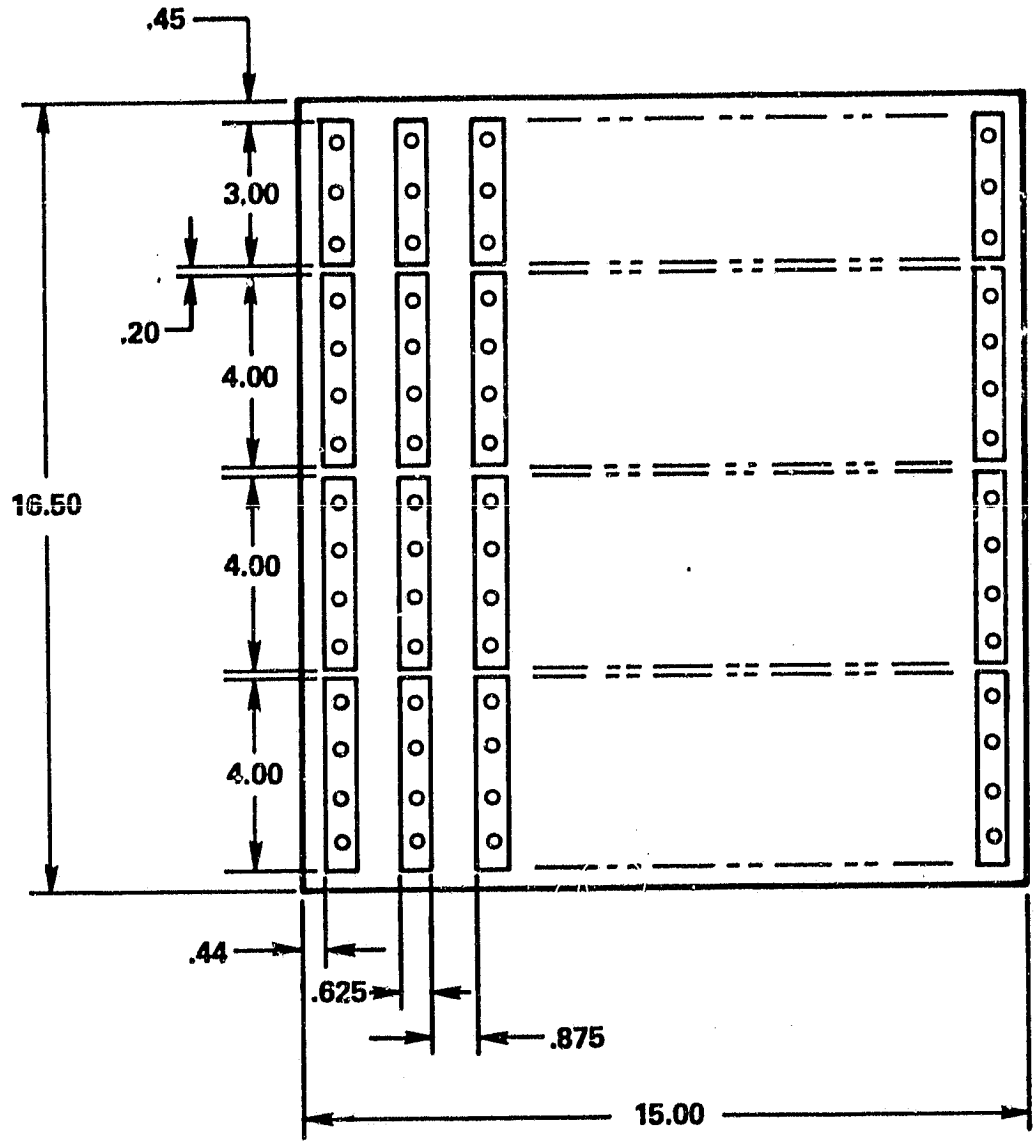


Figure 1. Meniscus Coater Web Holding Fixture

b. After application of P8, the strips were baked for 15 minutes at 150°C. After drying, the strips had a white-powdery surface.

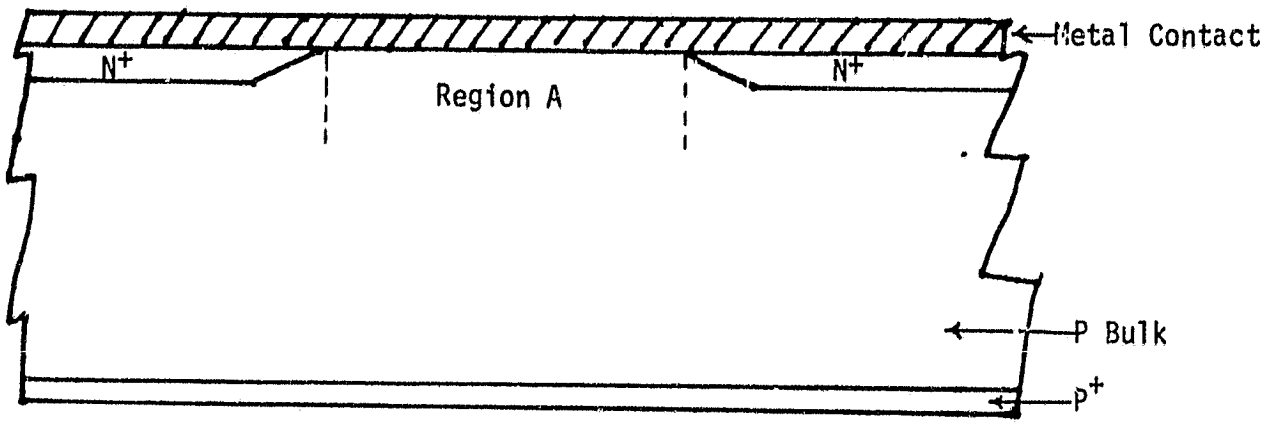
c. The strips were diffused for 20 minutes at 850°C in an 80% N_2 - 20% O_2 ambient. The powdery surface was still evident after diffusion.

d. After stripping (10% HF in deionized water), the N^+ surface appeared clean; but there were small, lightly adherent particles which could be brushed offf.

e. After the strips were coated, the residual P8 solution removed from the meniscus coater was distinctly yellow - as opposed to the original water-white color.

The sheet resistivity on the coated strips was measured after diffusion and showed a wide variability with a number of the strips having resistivities in excess of 1000 Ω/□ (the specification is 60 ±10 Ω/□). The high sheet resistivity noted was presumably due to (1) very thin or nonexistent coating on some strips or portions thereof, or (2) coating flaked off areas of strips during bake cycle. This would cause the observed low shunt resistance. Figure 2 is a sketch which shows how shunting could occur.

After diffusion, processing of all strips both gaseous $POCl_3$ and liquid P8 diffused was completed using baseline processes. Table 1 shows a comparison of lighted IV data from liquid P8 diffused cells and gaseous $POCl_3$ diffused cells fabricated on the same web crystal. Of the 10 web crystal pairs listed, in five cases the liquid P8 cells had significantly higher properties. In one case, the $POCl_3$ diffused cell was superior; and in four cases, the cells were essentially equal. When the liquid source diffused cells have higher efficiencies than the $POCl_3$ diffused cells, the major difference is a larger short circuit current.



NOTE: No N^+ diffusion or very shallow diffusion in Region A. Metal contact shorts N^+ and P regions giving a low R_{shunt}.

Figure 2. Sketch of Mechanism for Low Shunt Resistance Observed in First Liquid Phosphorus Experiment

TABLE 1

LIGHTED IV CELL DATA FROM INITIAL MENISCUS COATER, LIQUID PHOSPHORUS EXPERIMENT

(Process Runs 0203-1W and 0203-25W)

Web Crystal	Junction* Process	No. of Cells	Av. V_{oc} (V)	Av. I_{sc} (A)	Av. FF	Av. Eff. (%)
5.206-16	Liq P8	3	.574	.614	.786	14.1
	$POCl_3$	2	.578	.639	.782	14.8
1.224-15	Liq P8	3	.541	.577	.787	12.6
	$POCl_3$	3	.545	.579	.786	12.7
5.206-17	Liq P8	3	.568	.616	.774	13.8
	$POCl_3$	3	.568	.596	.773	13.3
1.224-18	Liq P8	5	.545	.604	.754	12.9
	$POCl_3$	1	.546	.626	.723	12.6
7.196-3	Liq P8	2	.562	.619	.786	13.9
	$POCl_3$	3	.552	.584	.795	13.3
1.225-3	Liq P8	3	.560	.610	.781	13.6
	$POCl_3$	1	.544	.575	.797	12.8
2.188-4	Liq P8	1	.537	.503	.810	11.0
	$POCl_3$	2	.525	.522	.783	10.9
1.207-2	Liq P8	1	.558	.600	.752	12.9
	$POCl_3$	2	.550	.584	.793	13.1
7.196-5	Liq P8	2	.577	.637	.779	14.6
	$POCl_3$	1	.550	.576	.783	12.7
4.188-6	Liq P8	3	.551	.596	.762	12.8
	$POCl_3$	2	.523	.530	.769	10.9

*Liq P8 = Diffusion Technology P8 phosphorus solution applied using meniscus coater.
$POCL_3$ = Baseline $POCl_3$ diffusion.

Table 2 shows lighted and dark IV data on 3 cells selected from this initial experiment. Note that the all-liquid source diffused cell (3B) has excellent junction properties and bulk lifetime. Cell 10C was also a liquid source diffused cell but had a high sheet resistivity and a very low shunt resistance.

Table 3 shows spreading resistivity measurements made on these same three cells to determine the N^+P junction depth. The slightly shallower junction with the liquid phosphorus diffused cell should increase current collection while the lower surface concentration would decrease the heavy doping (lattice strain) effects. The shallow junction depth on cell 10C reinforces the possible shunting mechanism discussed above and depicted in Figure 2.

Table 4 presents overall yield data from those runs which indicates no apparent yield penalty with the all liquid diffusion process.

This first test on the meniscus coater showed that high quality cells can be fabricated from liquid source diffusions. However, the uniformity of the coating must be improved. In addition, the diffusion temperature and time and the ambient gas composition must be optimized to obtain the required sheet resistance.

A second meniscus coater test was then carried out to study coating results when the dopant solution viscosity and the application speed were varied. Again, the dopant solution used was Diffusion Technology P8.

Since it was noted previously that the as-received dopant solution did not form a full meniscus over the top of the porous stainless steel cylinder, the liquid dopant was diluted by adding 25% (by volume) of isopropyl alcohol. Although improved, the coating applied to the strips along the width of the holding fixture was still not completely uniform. Adding an additional 25% of isopropyl alcohol increased the meniscus height sufficiently to produce a uniform coating. The remainder of the test run was made using this 50% isopropyl alcohol/50% as-received P8 solution.

TABLE 2

EXPANDED CELL DATA FROM FIRST MENISCUS COATER, LIQUID PHOSPHORUS EXPERIMENT

LIGHTED AND DARK IV DATA: ALL LIQUID JUNCTION CELLS VS $POCl_3$ BASELINE CELL

Web Crystal	Process	Cell No.	V_{oc}(V)	J_{sc}(mA)	FF	n(%)	R_s(Ω-cm^2)	R_{sh}(Ω-cm^2)	τ(μsec)	$J_{01}(\frac{A}{cm^2})$	$J_{02}(\frac{A}{cm^2})$
5.206-17	$POCl_3$	9A	.569	30.5	.765	13.3	0.11	7.6×10^3	69	6.6×10^{-12}	9.1×10^{-7}
5.206-16	Liq P8	3B	.577	31.3	.805	14.5	0.45	$7\overline{1}2.5 \times 10^3$	124	5.0×10^{-12}	8.4×10^{-8}
1.224-16	Liq P8	10C	.217	18.5	.564	2.3	-3.2	0.02×10^{-3}	Not calculated, out of range.		

Cell 9A has good junctions and adequate bulk lifetime; both R_s and R_{sh} are good.

Cell 3B has exceptional junctions and bulk lifetime; R_s and R_{sh} are good.

Cell 10C was a reject cell, apparently high sheet resistivity after N^+ diffusion; cell shows very low shunt resistance.

TABLE 3

N^+P JUNCTION DEPTH MEASUREMENTS ON SEVERAL LIQUID JUNCTION CELLS

Web No.	Cell No.	Process	Junction Depth (N^+P) (μm)	Surface Conc. (atoms/cm^3)
5.206-17	9A	$POCl_3$ Baseline	0.38	9×10^{19}
5.206-16	3B	Liquid P8	0.32	2.9×10^{19}
1.224-16	10C	Liquid P8	0.24	1.9×10^{19}

TABLE 4

YIELD DATA FROM INITIAL MENISCUS COATER, LIQUID PHOSPHORUS EXPERIMENT
Runs 0203-1W and 0203-25W

	No. of Cells Started	No. of Cells Tested	Mechanical Yield
Liquid Phosphorus	72	49	68%
Baseline $POCl_3$	72	49	68%
TOTAL	144	98	68%

For this second experiment, three batches of 24 strips of dendritic web were identified. These batches were first diffused to form a P^+P back junction using Diffusion Technology B60 liquid dopant. Prior to applying the liquid phosphorus on the meniscus coater, the strips were manually coated with a liquid SiO_2 diffusion mask using a sponge-squeegee.

Where possible, individual strips in each batch were separated into crystal pairs, and approximately one-half of the pairs were diffused using the baseline $POCl_3$ process to obtain comparative data. The baseline cells showed a sheet resistivity within specification and an average efficiency of 13.9% for 53 cells. The remainder of the pairs were separated into four groups and coated with the diluted P8 solution in the meniscus coater at application speeds of 7.5, 18, 28, and 36 cm/min. After coating, the strips were baked under a heat lamp for 10 minutes at 80°C and in a drying oven for 15 minutes at 200°C. Immediately before diffusion, they were held at the mouth of the furnace tube for 10 minutes at about 350°C.

Table 5 shows the effect of coating speed on the liquid dopant thickness as determined after the 200°C bake. These results are similar to those observed when an antireflective coating is applied to web material by withdrawing the strip from a liquid. That is, the slower the withdrawal speed, the thinner the coating.

Two of the three experimental batches were diffused at 870°C for 20 minutes in a gas flow of 225 cc/min O_2 and 100 cc/min N_2. The third batch was diffused at 877°C for 20 minutes in the same gas flow. After diffusion, the diffusion glass was removed from the strips and the sheet resistivity measured. Table 6 shows the results of these measurements. As was seen in the first meniscus coater test, the sheet resistivity varied greatly both along the strip and among the different strips. There was no obvious correlation between sheet resistivity and coating speed (thickness).

The average efficiency of all the liquid diffusant coated cells (about 10.5%) was significantly lower than the baseline processed cells. However, several of the liquid cells had properties equal to the $POCl_3$ diffused cells.

TABLE 5

EFFECT OF MENISCUS COATER APPLICATOR SPEED ON FILM THICKNESS

Applicator Speed (cm/min)	Estimated Thickness
7.5	<200 nm - generally colorless
18	red-green color ≈300-700 nm
28	some white powdery areas
36	thick, no color when dry (≈1 μm) white powdery surface

Note: All tests performed on dendritic web material using P8 liquid phosphorus solution.

TABLE 6

SHEET RESISTIVITY OF LIQUID COATED STRIPS FROM SECOND MENISCUS COATER LIQUID PHOSPHORUS EXPERIMENT

RUN 305-1W
(Diffused at 870°C - 20 min.)

Strip No.	Coating Speed (cm/min)	Sheet Resistivity Range along Strip (Ω/□)
1	18	120-2000
3	36	250-2000
5	18	700-1000
7	36	700-1000
9	18	50-200
14	18	44-500
15	18	90-2000
19	18	300-1500
21	36	500-2000
24	18	650-900

RUN 305-25W
(Diffused at 870°C - 20 min.)

25	28	700-800
27	28	600-1000
29	18	600-1200
33	28	500-800
36	18	400-1000
37	28	700-2000
38	28	38-1500 (P type surf.)
41	28	35-2000 (P type surf.)
43	28	34-2000 (P type surf.)
45	28	150-900
47	28	180-600
48	28	53-270

RUN 308-73W
(Diffused at 877°C - 20 min.)

73	7.5	45-750
74	7.5	35-1700
78	7.5	120-500
84	28	260-750
87	28	70-980
89	28	180-730
91	7.5	35-77
92	28	35-160
94	28	35-460
96	28	80-950

From this second meniscus coater test, the following conclusions were drawn:

- The meniscus coater can be used to apply uniform coatings of the liquid phosphorus containing solution of varying thicknesses.

- Although the overall average of the front junction liquid doped cells was lower than on the first test, several cells were equal to the baseline processed cells.

- The major task in the liquid doped front junction is to determine conditions for obtaining uniform sheet resistivities.

This work will be highlighted during the next reporting period.

2. Back Junction Formation Using a New Boron Containing Liquid

Several processing experiments have been made using a new boron containing solution from Allied Chemical (XB-150). This material is reported by the vendor to give more uniform sheet resistivities and has several processing advantages:

a. Solution is neutral and, thus, should not interact with any coating system parts,

b. Solution is insensitive to humidity, and

c. No prebaking is required prior to diffusion.

To date, two processing experiments have been completed using this material.

The boron diffusions in both cases were made a5 980°C for 20 minutes in an ambient of 98% N_2 - 2% O_2, with a total gas flow of 2000 cc/min. The gas composition was suggested by the vendor. Standard Westinghouse process sequences were used to complete cell processing operations in these experiments. In each run, roughly half of the cells were processed with the XB-150 solution and the remaining cells with the "baseline" B60 boron containing solution.

The first test contained a number of shunted cells apparently due to a processing problem, and the overall run quality was low.

The results of the second test were significantly better, and there were no cells rejected due to shunting. The overall cell data is shown below. All cells were 1.6 cm wide and 9.8 cm long.

Run 303-25M	No. of Cells	Av. Eff. (%)	Average Sheet Resistivity (Ω/□)
Entire Run	42	14.3 ±1.1	---
Baseline Cells	25	13.8 ±0.9	34 ±4
XB-150 BSF Cells	17	15.1 ±0.9	46 ±3

Table 7 shows a comparison of the two web crystal pairs included in the run. In this run, the XB-150 cells were significantly better than the baseline cells coated with the B60 solution. The major improvement is the higher current density in the XB-150 cells.

Further experiments are planned to verify these data; however, XB-150 would appear to be a suitable diffusion source for forming the P^+P back junction.

3. Test of Various SiO_2 and Boron Containing Liquids

During this period, comparative data were obtained on liquid SiO_2 and liquid boron solutions from four different vendors. The vendors and solutions are shown in Table 8.

In the experiment, the baseline diffusion temperatures and gas flows were used in all cases. Table 9 shows the results of these tests. The first eight columns identify the runs and the dopants together with sheet resistivity data. All of the samples produced cells with suitable sheet resistivity. The next three columns give the average dark IV data for the cells in the run. The last column (electrical rejects) are cells of the type discussed in the previous quarterly report on this contract*. The major cause of rejection was a low shunt resistance. The number of electrical rejects is a measure of the efficacy of the diffusion mask in preventing this shunting.

*Westinghouse TME 3186 submitted March 15.

TABLE 7

A COMPARISON OF ELECTRICAL PARAMETERS FROM PROCESS RUN 303-25M CRYSTAL PAIRS
(XB-150 VS BASELINE B60 LIQUID BORON)

Web Crystal	No. of Cells	Av. V_{oc} (V)	Av. Efficiency (%)
3.104-1 (XB-150)	3	.586	15.5
3.104-1 (B60)	3	.572	14.5
1.129-5 (XB-150)	3	.587	15.6
1.129-5 (B60)	2	.568	13.4

TABLE 8

SOLUTIONS USED IN LIQUID SiO_2/LIQUID BORON TESTS

Supplier	Liquid Mask Solution	Liquid Boron Solution
Filmtronics	700A	FB201
Emulsitone	B100	B201
Allied Chemical	X600*	XB150*
Diffusion Technology	U1A	B60

*These are experimental products.

TABLE 9

RESULTS USING VARIOUS LIQUID SiO_2 AND LIQUID BORON SOLUTIONS

Item No.	Proc. Run No.	P+P Mask	P+P Diffusant	P+P Sheet Res. (Ω/□)	N+P Mask	N+P Diffusant	N+P Sheet Res. (Ω/□)	IV (Avg. Values) Voc(V)	IV (Avg. Values) η (%)	YIELD No. of Cells Tested	YIELD No. of Electrical Rejects
1	217-73W	700A	FB201	40-50	700A	$POCl_3$	43-54	.571	14.2	58	7
2	217-49W	B100	B201	40-47	B100	$POCl_3$	45-57	.575	14.2	53	1
3	217-1W	X600	XB150	40-50	X600	$POCl_3$	45-55	.548	11.4	45	41
4	210-73W	X600	B60	30-40	X600	$POCL_3$	45-55	.556	13.1	51	27
5	214-73W	X600	B60	32-36	X600	$POCl_3$	44-52	.558	13.8	53	3
6	210-49W	U1A	B60	31-36	X600	$POCl_3$	44-55	.566	13.6	45	2
7	310-1M	U1A	B60	31-35	X600	$POCl_3$	48-52	.564	14.3	55	0
8	310-25M	U1A	B60	31-35	X600	$POCl_3$	45-58	.568	14.4	51	4
9	303-25M	U1A	XB150	42-50	U1A	$POCl_3$	45-55	.563	15.1	17	0
10	303-25M	U1A	B60	30-35	U1A	$POCl_3$	45-55	.565	13.8	25	0

In general, all the dopants tested were capable of producing good back surface fields which, in conjunction with the $POCl_3$ diffusion, yields high efficiency cells.

Only one liquid SiO_2 solution (X600, in Items 3 and 4 identified in Table 9) yielded cells with a very large number of reject cells. However, Item 5 which was the same process as Item 4 showed above average efficiencies. Since this is an experimental product, there may be an unknown problem in preparing the diffusion mask.

The data in Table 9 also suggest that the mask is much less important during $POCl_3$ diffusion than during the back surface diffusion. For example, Items 6, 7, and 8 used the standard U1A for the boron diffusion and the X600 for the $POCl_3$ diffusion. In all cases, these runs yielded good cells.

The XB-150, discussed in the previous section of this report, also appears to be a suitable boron dopant when used with U1A.

4. Pelletized Silicon for Replenishment During Web Growth

As reported previously, a silicon shot tower which was developed for JPL by Kayex Corporation under subcontract to Union Carbide Company was transferred to this contract. The transfer and subsequent operations were made on a "no-cost" basis to JPL. The purpose of the transfer was to facilitate an evaluation of dendritic web silicon grown from small Si pellets produced by the shot tower. This evaluation was made by processing dendritic web grown from shot into cells.

A number of successful runs were made, and the shot produced was used in web growth experiments. Based on properties of cells produced from these web growth runs, it was concluded that the pelletized shot does not degrade cell properties and is suitable for use as a replenishment material in the web growth furnaces.

Recently, Westinghouse was approached by a potential supplier of silicon pellets manufactured using an approach that did not employ a shot tower. The pellet sizes appeared equally applicable to the pellet feed mechanism currently in use on several of the pre-pilot line furnaces. A significant aspect of this manufacturer's material is that it can be procured in large quantities at a much lower price than semiconductor grade silicon. Since more expensive commercially available polycrystalline boules must first be sliced to smaller sizes and then used as input to the shot tower, the potential cost savings is very large.

To allow an evaluation of the material, a sufficiently large sample was left by the supplier to make numerous web growth runs. Web grown using some of the material has been processed into cells that can now be compared to cells produced from web grown from the standard silicon charge. For this evaluation, several web crystals were grown in the furnace melts prior to the introduction of pellets. Crystals were then grown during the remainder of the furnace runs using the pellets as replenishment material. With this procedure, the first web crystals grown were composed of the standard semiconductor grade silicon. The later web crystals, due to replenishment, contained an increasing fraction of silicon melted from the pellets. The crystals were then processed into solar cells using standard procedures.

The average efficiencies of cells made from web grown from the initial melt and after the introduction of pellets into the melt as replenishment material are given in Table 10. This web was included in many processing batches (some of which were part of ongoing experiments) and provided a relatively small population of cells. Although a larger data base is required, it is tentatively concluded that this replenishment material is of excellent quality. Further use and evaluation of this material will continue.

5. Ion Implantation Compatibility/Feasibility Study

Initial ion implantation experiments have been completed by Spire Corporation using dendritic web supplied to JPL under this contract, and the first quarterly report has been issued.*

*Quarterly Report QR-10085-01 from JPL Contract 95[illegible]81

TABLE 10

AVERAGE EFFICIENCIES OF CELLS GROWN IN RUNS USING SILICON PELLETS AS REPLENISHMENT MATERIAL

Condition	Cell Size (cm x cm)	No. of Cells	Average Efficiency, %
Initial Melt	1.6 x 9.8	17	12.6 ±2.4
After Replenishment	1.6 x 9.8	48	13.6 ±1.9
Initial Melt	2.0 x 9.8	21	12.2 ±2.1
After Replenishment	2.0 x 9.8	43	13.2 ±1.5

Due to concerns relative to cleaning procedures used prior to ion implantation, these initial results are suspect. Accordingly, a second batch of dendritic web material grown in the AESD web growth furnaces was cleaned using standard Westinghouse procedures, cut to 2.1 cm x 5.0 cm blanks, and shipped to Spire for further ion implantation work.

IV. ACTIVITIES PLANNED FOR NEXT QUARTER

A. Optimize liquid phosphorus dopant diffusion parameters

B. Show feasibility of using meniscus coater for application of liquid phosphorus source

C. Continue cost analysis on all liquid dopant source process sequence

V. PROGRAM DOCUMENTATION AND DELIVERABLES STATUS

All programmatic and technical documentation specified in the subject contract (955909) have been prepared and submitted in accordance with contract schedular requirements. Table 11 summarizes submittal status of all routine reports (financial and monthly/quarterly technical reports). Table 12 summarizes submittal status of topical and summary reports.

Table 13 summarizes the delivery of dendritic web material and solar cells made in accordance with contract specifications. Note that the latest material shipment was made directly to Spire Corporation for ion implantation work described in Section III.5 of this report.

TABLE 11

ROUTINE PROGRAM DOCUMENTATION SUBMITTAL STATUS

Item	Submittal Date
1. Monthly Technical Reports	
A. March 1982	April 1, 1982
B. April 1982	May 3, 1982
C. May 1982	June 3, 1982
D. June 1982	July 8, 1982
E. July 1982	August 2, 1982
F. August 1982	September 7, 1982
G. September 1982	October 7, 1982
H. October 1982	November 8, 1982
I. November 1982	December 6, 1982
J. December 1982	January 10, 1983
K. January 1983	February 1983
L. February 1983	March 7, 1983
M. March 1983	April 11, 1983
N. April 1983	May 5, 1983
O. May 1983	June 13, 1983
2. Financial Management Reports	
A. March 1982	April 6, 1982
B. April 1982	May 19, 1982
C. May 1982	June 14, 1982
D. June 1982	July 16, 1982
E. July 1982	August 16, 1982
F. August 1982	September 14, 1982
G. September 1982	October 15, 1982
H. October 1982	November 15, 1982
I. November 1982	December 15, 1982
J. December 1982	January 14, 1983
K. January 1983	February 16, 1983
L. February 1983	March 16, 1983
M. March 1983	April 15, 1983
N. April 1983	May 11, 1983
O. May 1983	June 16, 1983
3. Quarterly Progress Reports	
A. No. 1 (MEPSDU)	March 15, 1981
B. No. 2 (MEPSDU)	June 15, 1981
C. No. 3 (MEPSDU)	September 15, 1981
D. No. 4 (MEPSDU)	December 15, 1981
E. No. 1 (Process Research)	June 16, 1982
F. No. 2 (Process Research)	September 16, 1982
G. No. 3 (Process Research)	December 16, 1982
H. No. 4 (Process Research)	March 16, 1983

TABLE 12

TOPICAL/SUMMARY PROGRAM DOCUMENTATION STATUS

Item	Submittal Date
1. Program Plan, Cost Estimates & WBS	
A. Original (MEPSDU)	December 17, 1980
B. Rev. 1 (MEPSDU)	May 22, 1981
C. Rev. 2 (MEPSDU)	January 8, 1982
D. Original (Process Research)	March 12, 1982
E. Rev. 1 (Process Research)	May 26, 1982
2. Design Review Packages	
A. Preliminary Design Review (MEPSDU)	February 19, 1981
B. Module Design Review (MEPSDU)	June 30, 1981
3. MEPSDU Summary Report	
A. Draft	June 3, 1982
B. Final	July 26, 1982
4. Technical Feasibility Reports	
A. Liquid Junction	January 10, 1983
B. Liquid Mask	May 13, 1983

TABLE 13

STATUS OF DENDRITIC WEB AND SOLAR CELL DELIVERIES TO JPL

Delivery Date	Web Length	No. of Cells
June 30, 1982	200"	20
September 14, 1982	200"	24
November 11, 1982	200"	--
January 10, 1983	271"	--
April 26, 1983	200"	24
May 11, 1983	200"	24
May 24, 1983*	240"	--

*Material sent directly to Spire Corporation for JPL ion implantation (Contract 956381) work.